Table 14 - Summary of Separation Distances for MSS Operations Channels Adjacent to Metsat Systems

Meteorological Receiver and Type of Associated Satellite GSO:Geostationary Satellite Orbit LEO: Low Earth Orbit	Separation Distance MSS Off-tuned 4 kHz Adjacent Channel		Separation Distance MSS NB Noise Floor in Adjacent Channel		Separation Distance MSS SS Noise Floor in Adjacent Channel	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
GOES Forecast Center (GSO)	6.5	0	0.9	.1	.2	0
GOES WB (GSO)	2.1	0	0.1	0	0	0
NOAA CDA (LEO)	2.0	0	0	0	0	0
NOAA KLM HRPT (LEO)	3.6	0	0.3	0	0	0
NOAA OPQ HRPT (LEO)	3.6	0	0.3	0	0	0
Meteosat SDUS (GSO)	6	1.9	0.7	0.1	0.1	0
Meteosat CDA/DATTS (GSO)	17	10.4	7.0	2.5	3.1	0.6
GMS CDA (GSO)	0	0	0	0	0	0
GMS VISSR (GSO)	0	0	0	0	0	0
Metaids (balloon)	3	0	0	0	0	0

Note:

1. NB - Narrowband, WB - Wideband, SS - Spread Spectrum
2. Calculations were performed with an MSS EIRP of -35 dBW/4 kHz and -43 dBW/1.25 MHz for narrowband and spread spectrum modulations, respectively.

Table 15 - Approaches on Sharing Between MSS and Meteorological Systems

MSS Operating Constraint	Applicability
Frequency Avoidance	Workable with respect to any meteorological system provided that there is a low probability of perceptible interference from a frequency-offset mobile earth station.
Co-Channel Time Sharing	Workable only on frequencies used only by meteorological systems that operate on a part-time schedule (e.g., LEO METSAT downlinks).
Co-Channel Geographic	Workable only with respect to meteorological stations at known locations and only for mobile earth stations known to be located beyond interfering range.

Table 16 - Summary of Analysis Input Parameters and Results for Meteorological System Interference to MSS Narrowband Systems

Meteorological Transmission and Type of Associated Satellite GSO: Geostationary Satellite Orbit LEO: Low Earth Orbit	MSS Earth Station EIRP (dBW)	Meteoro. System EIRP (dBW)	Metsat Antenna Discrimination To Edge of Earth (dB)	MSS Receive Bandwidth (kHz)	Meteoro. Emission Bandwidth (kHz)	MSS Carrier Power (dBW)	Interference Power (dBW)	C/I (dB)
GOES Forecast Center (GSO)	15 dBW	27.9	3	4.22	26	-146.6	-166.5	19.9
GOES WB (GSO)	15 dBW	27.9	3	4.22	25000	-146.6	-196.3	49.8
NOAA CDA (LEO)	15 dBW	10	0	4.22	5334	-146.6	-199.2	52.6
NOAA KLM HRPT (LEO)	15 dBW	10	0	4.22	2668	-146.6	-196.2	49.6
NOAA OPQ HRPT (LEO)	15 dBW	14.7	0	4.22	2500	-146.6	-192.6	46.1
Meteosat SDUS (GSO)	15 dBW	6.5	3	4.22	26	-146.6	-187.7	41.1
Meteosat CDA/DATTS (GSO)	15 dBW	21.3	3	4.22	660	-146.6	-201.9	55.4
GMS CDA (GSO)	15 dBW	59	3	4.22	20000	-146.6	-194.3	47.7
GMS VISSR (GSO)	15 dBW	4	3	4.22	260	-146.6	-175.4	28.8
MetAids (balloon)	15 dBW	2	0	4.22	15	-146.6	-181.1	34.5
MetAids (balloon)	15 dBW	2	0	4.22	400	-146.6	-195.4	48.8

Table 17 - Summary of Analysis Input Parameters and Results for Metsat Interference to MSS Spread Spectrum

Meteorological Transmission and Type of Associated Satellite GSO: Geostationary Satellite Orbit LEO: Low Earth Orbit	MSS Earth Station EIRP (dBW)	Metsat Satellite EIRP (dBW)	Metsat Antenna Discrimination To Edge of Earth (dB)	MSS Receive Bandwidth (kHz)	Metsat Emission Bandwidth (kHz)	Received MSS Carrier (dBW)	Received Metsat Interference (dBW)	C/I (dB)
GOES Forecast Center (GSO)	15 dBW	27.9	3	1250	26	-146.6	-158.6	12.0
GOES WB (GSO)	15 dBW	27.9	3	1250	25000	-146.6	-171.6	25.0
NOAA CDA (LEO)	15 dBW	10	0	1250	5334	-146.6	-174.5	27.9
NOAA KLM HRPT (LEO)	15 dBW	10	0	1250	2668	-146.6	-171.4	24.9
NOAA OPQ HRPT (LEO)	15 dBW	14.7	0	1250	3500	-146.6	-167.9	21.4
Meteosat SDUS (GSO)	15 dBW	6.5	3	1250	26	-146.6	-179.8	33.2
Meteosat CDA/DATTS (GSO)	15 dBW	21.3	3	1250	660	-146.6	-180	33.4
GMS CDA (GSO)	15 dBW	59	3	1250	20000	-146.6	-169.5	23.0
GMS VISSR (GSO)	15 dBW	4	3	1250	260	-146.6	-157.5	10.9
MetAids (balloon)	15 dBW	2	0	1250	15	-146.6	-175.6	29.0
MetAids (balloon)	15 dBW	2	0	1250	400	-146.6	-175.6	29.0

Table 18 - Meteorological Receiver Parameters

Parameter	Microdyne	Telonics
Model	1400 R	TIRIS e/s
Frequency Range	1650-1720 MHz	1690-1710 MHz
Antenna Diameter	CDA: 25.9 m HRPT: 2.44 m WEFAX: 2.44 m	CDA: 25.9 m HRPT: 1.2 m (3) WEFAX: 2.44 m
Antenna Gain	CDA:46.8 dBi HRPT: 29 dBi WEFAX: 30 dBi	CDA:46.8 dBi HRPT:24.1 dB (3) WEFAX: 30 dBi
Antenna Temperature	≤ 200 K	
Beamwidth	3 dB 5°	1 dB 7° (3) 3 dB 13°
LNA Noise Figure / Gain	1 dB / 40 dB [1]	
LNA Noise Temperature		50 K
LO Frequency	180 MHz, 20 MHz	
IF	160 MHz, 20 MHz	137 MHz
IF Rejection	80 dB	
3 dB Bandwidth	CDA: 6 MHz HRPT: 3.3 MHz WEFAX: 30 kHz	
Selectivity	NOAA: 60/3 dB ratio of 4:1 max WEFAX: 30/3 dB ratio of 7:1 max	
1 dB Compression Point	-10 dBm (est.)	-15 dBm @ LNA input
Third Order Intercept	+5 dBm (min)	-5 dBm
Dynamic Range	Noise Threshold to -10 dBm	
Image Rejection	60 dB min, 80 dB typ	
Spurious Rejection	60 dB min	
System Noise Temperature	210 K (calc)	90 K (typ)
Receiver Noise Figure	12 dB	
Receiver Sensitivity (calc)	CDA: -88.2 dBm HRPT: -90.8 dBm WEFAX: -105.2 dBm	-110 dBW ≤80 dBm
System Sensitivity (calc)	CDA: -97.8 dBm HRPT: -100.4 dBm WEFAX: -114.8 dBm	CDA: -99.0 dBm HRPT: -101.6 dBm WEFAX: -122 dBm (2)
C/N or S/N @ Acquisition	-15 dB C/N in IF and +6 dB SNR in PLL whichever limits 1st	6 dB S/N
AGC	input thermal noise is linear within 30 dB range from +10 dB S/N to -10 dBm	

NOTES:

1. Preamplifier is asserted to be typical based on Datron system which is centered around a Microdyne system.
2. The Telonics receiver is relatively new and currently is only designed to receive HRPT. In anticipation of future models that will use a similar low-noise design, the sensitivities for a CDA and WEFAX receiver are derived.
3. Part of Telonics TIRIS package.

Table 19 - MSS Mobile Earth Terminal Parameters

Parameter	Narrowband Transmission
Transmitter Output Power	6 dBW
Transmitter Mainbeam Antenna Gain	9 dBi
Antenna Gain Toward Horizon	4 dBi
Met Antenna Pattern	omni
Emission 3 dB Bandwidth	2.97 kHz
Modulation	QPSK
Noise Bandwidth	4.22 kHz

Table 20 - Separation Distances to Limit MSS Power Levels to Less Than the Required Receiver Saturation Level

Meteorological Earth Station Type	Receiver Antenna Attenuation	Receiver Antenna Off-axis Angle	Separation Distance from Microdyne Receiver at Sensitivity	Separation Distance from Telonics Receiver at Sensitivity
CDA	32.3	5°	18 m	32 m
HRPT	10.7	5°	30.5 m	54.5 m
WEFAX	10.7	5°	31.5 m	55.5 m
CDA	39.8	10°	7.6 m	13.5 m
HRPT	14.2	10°	20.5 m	36.5 m
WEFAX	14.2	10°	21 m	37.2 m
CDA	56.8	Backlobe	1.1 m	1.9 m
HRPT	31.2	Backlobe	3 m	5.2 m
WEFAX	31.2	Backlobe	3 m	3 m

Table 21 - Amount of Desense for Various Desired and Interfering Signal Levels

Desired Signal Above Sensitivity	MSS Signal Level Above Saturation	Desense Rate	S/N without Interference	S/N with Interference	Amount of Change in RF Gain
2	2	0.26	8	0.3	7.7
2	4	0.26	8	-7.4	15.4
2	6	0.26	8	-15.1	23.1
2	10	0.26	8	-30.5	38.5
4	2	0.42	10	5.2	4.8
4	4	0.42	10	0.5	9.5
4	6	0.42	10	-4.3	14.3
4	10	0.42	10	-13.8	23.8
6	2	0.54	12	8.3	3.7
6	4	0.54	12	4.6	7.4
6	6	0.54	12	0.9	11.1
6	10	0.54	12	-6.5	18.5
10	2	0.7	16	13.1	2.9
10	4	0.7	16	10.3	5.7
10	6	0.7	16	7.4	8.6
10	10	0.7	16	1.7	14.3

Table 22 - Separation Distances Between a Microdyne Meteorological Receiver and an MSS Earth Terminal Required to Limit MSS Signal Levels to Sensitivity

Meteorological Earth Station Type	Receiver Antenna Attenuation	Receiver Antenna Off-axis Angle	Separation Distance at Sensitivity
CDA	32.3	5°	440 m
HRPT	10.7	5°	1000 m
WEFAX	10.7	5°	5414 m
CDA	39.8	10°	186 m
HRPT	14.2	10°	674 m
WEFAX	14.2	10°	3618 m
CDA	56.8	Backlobe	26 m
HRPT	31.2	Backlobe	95 m
WEFAX	31.2	Backlobe	511 m

Table 23 - Separation Distances Between a Telonics Meteorological Receiver and an MSS Earth Terminal Required to Limit MSS Signal Levels to Sensitivity

Meteorological Earth Station Type	Receiver Antenna Attenuation	Receiver Antenna Off-axis Angle	Separation Distance at Sensitivity
CDA	32.3	5°	505 m
HRPT	10.7	5°	1157 m
WEFAX	10.7	5°	1240 m
CDA	39.8	10°	213 m
HRPT	14.2	10°	774 m
WEFAX	14.2	10°	8289 m
CDA	56.8	Backlobe	30 m
HRPT	31.2	Backlobe	109 m
WEFAX	31.2	Backlobe	1171 m

Table 24 - Separation Distance Between a Microdyne Meteorological Receiver and an MSS Earth Terminal Required to Limit MSS Spurious Emission Levels in the Receiver Passband

Meteorological Earth Station Type	MSS Spurious Emission Level	Receiver Antenna Attenuation	Receiver Antenna Off-axis Angle	Separation Distance at Permissible Interference Level
CDA	63	32.3	5°	160 m
HRPT	63	10.7	5°	2418 m
WEFAX	63	10.7	5°	6974 m
CDA	63	39.8	10°	67 m
HRPT	63	14.2	10°	1616 m
WEFAX	63	14.2	10°	4661 m
CDA	63	56.8	Backlobe	10 m
HRPT	63	31.2	Backlobe	228 m
WEFAX	63	31.2	Backlobe	658 m

Table 25 - Cosite Sharing Criteria Used for Meteorological Receivers

Earth Station Type	Sharing Criteria
CDA	-92 dBm
HRPT	-111 dBm
WEFAX	-120 dBm

Table 26 - Probability of Potentially Perceptible Interference

Earth Station Type	Contour Area	Probability of Interference
CDA	.00142 km^2	2E-8
HRPT	.5298 km^2	7.3E-6
WEFAX	3.27616 km^2	4.5E-5

Annex II
to
Technical Appendix

Frequency Sharing Between Domestic MSS (space-to-Earth) Systems and Mobile Aeronautical Telemetry (MAT) Systems in the 1492-1535 MHz Band

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LIST OF ILLUSTRATIONS

MAT systems from foreign Broadcasting-Satellite (sound) systems that may operate under an allocation adopted by WARC-92 in the 1452-1492 MHz segment of the subject band. Ref. 3 conveys the results of these MAT studies, which address worst-case sharing situations in order to ensure that coordination will be triggered with respect to US MAT operations in all cases where there is any possibility of unacceptable interference. AMSC has monitored these studies in order to obtain information on MAT systems in support of an updated analysis of the subject sharing situation. The assumptions and findings in the analyses that follow are consistent with those of the MAT study (Ref. 3), and the objectives of these studies are complementary. That is, this report presents the results of the initial coordination analyses that would be triggered under the guidelines in Ref. 3.

1.2 Objective

The objective of this study was to define design and operating constraints that may be necessary to prevent unacceptable interference between a geostationary MSS system and MAT systems operating in the 1492-1525 MHz band. Insofar as the technical results are also applicable to the sharing at 1525-1535 MHz, the results may also indicate conditions under which MAT links may continue to operate satisfactorily in that band (different assumptions regarding MSS system characteristics may be warranted as a result of the worldwide MSS allocation, e.g., use of satellite antennas that generate global-coverage beams).

1.3 Approach and Report Overview

Figure 1 illustrates the overall analysis approach. In order to quantify the potential interference to MAT systems, the performance achieved by MAT systems was evaluated with and without a co-channel MSS downlink signal being present. These results were compared with the criteria for acceptable interference that is defined in Section 2. Specifically, using representative system parameters and spread sheet software defined in Attachment 1, and assuming co-channel sharing in the same geographic area, the analysis determined ratios of carrier-to-noise power (C/N) and carrier-to-noise plus interference power (C/[N+I]) for the MAT system during instants of time when the MAT signal is not faded. The effects of fading of the desired signal and variability of the interfering signal power were examined (Section 4) using the methodology described in Attachment 1.

Potential interference from MAT transmissions to mobile earth stations was quantified in terms of nominal required separation distances for co-channel operation (Section 5). Moderate fading was assumed on the interfering signal path. A 1 dB reduction in MSS power margin was assumed to be acceptable.

Table 1 lists the system parameters used for the initial C/N and C/[N+I] calculations. The assumed 2.44 m and 10 m MAT receiver antennas are the smallest and largest antennas typically used at the sites that were considered. The assumed test aircraft antenna input power and gain levels yield an EIRP level that is among the lowest values characterized in Ref. 3. The assumed MSS PFD (-126.5 $dBW/m^2/4$ kHz) impinging on the MAT receiver is approximately the highest level that may be desired by AMSC for any service, including service to handheld terminals. (A substantially lower PFD level would enable high-quality service to vehicular and transportable mobile earth stations.) Significantly, the MSS system cannot share frequencies with another MSS system covering the US (i.e., the PFD generated by any other MSS system in the MAT operating area under consideration must be at least 18 dB lower than the PFD of the MSS system under consideration). Thus, the entire interference budget for the MAT link under consideration is allocated to the subject MSS system.

The overall results were interpreted for the co-channel sharing situation and extrapolated to sharing involving frequency offsets between MAT and MSS signals, multiple MSS signals, geographic separation between areas where MAT systems and MSS downlinks are operated, alternate MSS satellite locations, and limitations on the services provided by the MSS system (Section 6).

Table 1 - Assumed System Parameters for Aeronautical Telemetry and MSS Systems

Link	Parameter	Value
Aeronautical Telemetry	Maximum Range	320 km
	Maximum Altitude	20 km
	Transmitter Antenna Input Power	3 dBW
	Transmitting Antenna Gain	0 dBi
	Frequency	1500 MHz
	Earth Station Antenna Gain	2.44 m - 29 dBi 10 m - 41.3 dBi
	Receiver Noise Temperature	200 K
	Bandwidth	1 MHz
	Earth Station Locations	60 primary and secondary sites nationwide
MSS	Satellite Longitude	101° W
	Transmitter Antenna Input Power	3.5 dBW
	Transmitting Antenna Gain	32 dBi
	Frequency	1500 MHz
	Acceptable Interference Power	-173.7 dBW/4.22 kHz at antenna output
	Mobile Earth Station Antenna Gain	0 dBi minimum, 9 dBi maximum
	Bandwidth	3.375 kHz (main lobe) 4.22 kHz (receiver noise)

Figure 1 - Analysis Approach

COMPILE TEST RANGE AND MAT DEPLOYMENT, EQUIPMENT AND OPERATING PARAMETERS AND DEFINE MSS BASELINE SYSTEM	ITU-R Doc. 8D/157 (Add.1) supplies the MAT equipment and deployment parameters that should be assumed for initial analysis. Worst-case MAT operating parameters are assumed initially. Parameters of current AMSC satellite and mobile earth stations are used.
↓	
DETERMINE PERMISSIBLE LEVELS OF INTERFERENCE TO MAT LINKS & MOBILE EARTH STATIONS	Assume a threshold level of the ratio of unfaded carrier-to-noise plus interference power (C/[N+I]) and describe N+I/N criteria that allows the interfering signal power (I) to occasionally reduce C/[N+I] to the minimum required value.
↓	
CALCULATE GEOMETRIC AND ANTENNA GAIN PARAMETERS FOR MAT LINKS VERSUS 101° SATELLITE LOCATION	Determine MAT receiver antenna discrimination toward the satellite and range to the aircraft for two geometric cases: (1) aircraft at maximum range from the MAT receiver with the minimum associated MAT receiver antenna discrimination, and (2) MAT receiver antenna pointed at the satellite (i.e., no discrimination) with the aircraft at maximum altitude.
↓	
FOR A SINGLE MSS CHANNEL THAT IS CO-CHANNEL WITH MAT, CALCULATE LEVELS OF INTERFERENCE TO MAT AND COMPARE WITH PERMISSIBLE LEVELS	This is the worst-case tuning situation for one MSS channel interfering with MAT.
↓	
CONSIDER A POTENTIAL AIRCRAFT FLIGHT PATTERN AND DETERMINE THE POTENTIAL STATISTICS OF INTERFERENCE TO MAT	This reveals the potential overall impact of the interference on availability of the MAT transmissions.
↓	
CALCULATE NOMINAL DISTANCE SEPARATIONS REQUIRED BETWEEN RECEIVING MOBILE EARTH STATIONS AND TRANSMITTING MAT AIRCRAFT	This reveals the sharing constraints that may be needed for protection of mobile earth stations from MAT transmissions.
↓	
INTERPRET RESULTS FOR ALL TEST RANGES AND MAT LINK	Consider effects of off-tuning of the MAT and MSS channels and operation of multiple MSS channels.

2. INTERFERENCE CRITERIA FOR MAT RECEIVERS

2.1 Minimum Required C/(N+I)

MAT systems use various modulation and data coding techniques that impart a broad range of required C/N levels at the MAT receiver antenna port. In Ref. 3, it is indicated that PCM/FM is commonly used and that the typical required C/N is 9 - 15 dB. This is corroborated by Ref. 4, which also suggests that a C/N of 12 dB should be assumed for FM telemetry systems (page 3.9-7). A Bit Error Ratio (BER) of the order of 10^{-5} or better (i.e., a high quality level for continuous telemetry) is achievable with a C/N of 12 dB for most coding, modulation and demodulation techniques, including allowances for implementation losses. Thus, assuming noise-like interference (I), a C/[N+I] of 12 dB is assumed to be the threshold for meeting MAT transmission quality objectives for long-term performance. The MSS signals may cause less interference than noise of equal power, but it is conservatively assumed that the MSS signals are noise-like.

2.2 Minimum Required Availability in the Radio Path

The term radio path *availability*, as used in this report, is the probability that the C/N or C/[N+I] is at or above the C/N or C/[N+I] level that maintains synchronization in the MAT link. The probability of exceeding the 12 dB threshold level identified in Section 2.1 must exceed the availability for adequate performance. The availability (a probability or percentage of time) is tantamount to a radio path outage (i.e., loss of telemetry link synchronization, which may occur with a C/N or C/[N+I] less than 4-8 dB).

Ref. 3 does not specify a minimum required availablity (as defined above) or probability for exceeding a certain transmission quality level in the radio path (e.g., 12 dB C/[N+I]). However, in discussing a concept of "excess margin" that can be consumed by interference, Section 6.4.2 of Ref. 3 states that a margin of 24.8 dB is needed to obtain the desired availability in an example MAT link that experiences severe Rayleigh fading, but this margin is specified with respect to the desired level of performance (i.e., 12 dB) rather than the threshold for link synchronization. In addition, the 24.8 dB margin is achievable in that example link only when the test aircraft is located near the minimum range from the MAT receiver. Thus, in that example, the desired "availability" is not achieved at larger operating ranges that constitute most of the flight time, and "excess margin" does not provide a basis for establishing unavailability budgets with allowances for interference. In such cases, the acceptable reduction in availability due to interference should be consistent with established norms for other services.

Based on criteria for other services such as the fixed-satellite service, it is assumed that 35% or more of the probability of not achieving the desired level of MAT radio path quality (C/N or C/[N+I] of 12 dB) may be caused by interference. In other words, the inherent probability of not achieving the desired quality (C/N) in a MAT link may be increased by about 54% due to interference. The inherent probability of not achieving the desired level of quality is determined with respect to the 12 dB minimum C/N with the test aircraft operating at maximum range from the MAT receiver.

3. INTERFERENCE POWER CALCULATIONS FOR WORST-CASE TEST AIRCRAFT LOCATIONS AND NOMINAL SIGNAL LEVELS

Two deployment scenarios for aeronautical telemetry aircraft were analyzed for each of 66 MAT receiver sites that were identified in a draft version of Ref. 3 (the final version of Ref. 3 lists 58 sites that are included among the 66 sites considered in this analysis). The first scenario (Geometry 1) puts the test aircraft at its maximum altitude (20 km) and at maximum range from the MAT receiver (320 km) with the MAT receiver antenna pointed in the azimuth of the MSS satellite. The off-axis gain of the MAT receiver antenna toward the satellite was calculated using the off-axis angle (difference in elevation angle) and the antenna patterns given in Attachment 1. Using this gain, the C/[N+I] was calculated for 2.44 m and 10 m MAT receiver antennas. The second scenario (Geometry 2) assumes the aircraft is at maximum altitude with the satellite in the boresight of the 2.44 m and 10 m MAT receiver antennas (i.e., the MAT antenna has no discrimination toward the MSS satellite).

Spread Sheets 1 and 2 in Attachment 2 present the calculations of unfaded C/N and C/(N+I) levels for Geometries 1 and 2 with MAT receiver antennas of 2.44 m and 10.0 m diameter. The MSS signal is assumed to be at its peak, instantaneous power level. Table 2 summarizes the key results, including those for the most-affected and least affected MAT receiver sites.

Table 2 - Summary of C/N and C/[N+I] Calculations

MAT Receiver	C/[N+I]		Reduction in C/N	
Site(s)	Geometry 1	Geometry 2	Geometry 1	Geometry 2
Minimum C/[N+I] Site(s), 2.44 m MAT Receiver Antenna (Hawaii, 159.7° West, 22° North)	27.0 dB	24.5 dB	4.5 dB	22.2 dB
Maximum C/[N+I] Site(s), 2.44 m MAT Receiver Antenna	30.7 dB at many sites	30.7 dB at many sites	0.8 dB at many sites	22.5 dB at many sites
Average Among Sites, 2.44 m MAT Receiver Antenna	30.0 dB	30.0 dB	1.0 dB	22.5 dB
Minimum C/[N+I] Site(s), 10 m MAT Receiver Antenna (Hawaii, 159.7° West, 22° North)	42.1 dB	24.5 dB	1.6 dB	34.4
Maximum C/[N+I] Site(s), 10 m MAT Receiver Antenna	43.5 dB at many sites	30.7 at many sites	0.3 dB at many sites	34.6 dB at many sites
Average Among Sites, 10 m MAT Receiver Antenna	43.3 dB	30.0 dB	0.5 dB	34.8 dB

Overall, there is very low variance in the values of minimum instantaneous C/[N+I] among the sites that were considered. The peak interference levels can be further summarized as follows:

- The highest instantaneous levels of interference (i.e., lowest C/[N+I] levels) occur under Geometry 2 (MAT receiver antenna pointed at MSS satellite). The resulting C/[N+I] levels in this "conjunction" geometry are independent of MAT receiver antenna size because the C/I ratio is independent of MAT receiver antenna size and the interfering signal power is much higher than the MAT receiver noise power. Fade margins of 11-19 dB exist during these conjunctions.

- In geometry 1, interference decreases with increasing diameter of the MAT receiver antenna.

- Consistent with the above C/[N+I] trends, the reduction in C/N increases with decreasing antenna diameter in Geometry 1 but decreases with antenna diameter in Geometry 2.

4. POTENTIAL STATISTICS OF INTERFERENCE TO MAT LINKS

4.1 Desired Signal Fading

Table 3 summarizes the potential fading characteristics of a cross-section of MAT links. The Rice-Nakagami fading distribution is associated with medium performance links. It is a mixture of the Rayleigh and Rician fading characteristics associated with links having relatively low and high availability. The ensuing statistical considerations address only the Raleigh faded links in which relatively low transmission quality is achieved. Many MAT links may achieve higher availability and be substantially less affected by the assumed MSS signal.

Table 3 - Performance of MAT Links in Terms of Signal Fading

Characterization of MAT Link	Type of Signal Fading and Fading Margin	MAT Transmitting Antenna Installation
low margin needed to obtain BER ($< 10^{-5}$) over short intervals of time	Rician, K >25 dB	Normally unobstructed transmitting antenna location on aircraft fuselage.
moderate margin needed to obtain BER ($< 10^{-5}$) over short intervals of time	Rice-Nakagami	Transmitting antenna often briefly obstructed.
high margin needed to obtain BER ($< 10^{-5}$) over most short intervals of time	Rayleigh exponent <-3.0	Normally obstructed transmitting antenna location on aircraft, missile or launch vehicle.

4.2 Variability of Interfering Signal Power

As described in Attachment 1, the MSS signal level at the MAT receiver antenna will vary over time as a result of MAT antenna motion and transmission duty factor. The duty factor effect of is not considered with respect to a single interfering signal because to do so could understate the statistics of potential interference; however, this factor can be considered in accordance with the Central Limit Theorem of Statistics when extrapolating results to multiple MSS signals. To further avoid understating the potential interference statistics, fading of the interfering signal is disregarded. This is a reasonable assumption because the MSS signals likely would exhibit Rician fading with high K values and, given that only the low performance MAT links of Table 3 are being analyzed, the statistics of C/[N+I] would be dominated by the statistics of the desired signal level.

The "S parameter" method introduced in Ref. 3 and elaborated upon in Attachment 1 yields the statistics of the received interfering signal power due to MAT antenna motion, as given below in Tables 4 and 5 for Geometries 1 and 2. The elevation angle from the MAT receiver antenna to the MSS satellite is assumed to be 40°, which is the nominal average value among all sites. Using the method of Ref. 3, the nominal angular area scanned by the MAT receiver antenna beam in relation to the angle of arrival of the MSS signal is 0.63 steradians. This estimated scan area is probably about the minimum area actually scanned by a MAT antenna beam, which would yield conservative overestimation of the probability of occurrence of a given interfering signal power level.

For Geometry 1 (Table 4), the test aircraft is located at its maximum range from the MAT receiver and the interfering signal power is near its minimum unfaded level due to the large off-axis angles between the MSS satellite and the mainbeam of the MAT receiver antenna. For segments of flight paths with the test aircraft near the maximum range from the MAT receiver, only small decreases in interfering signal power are possible due to MAT antenna motion. For Geometry 2 (Table 5), the test aircraft is located near its minimum range from the MAT receiver and the interfering signal power is at its peak level due to the conjunction of the MAT receiver, test aircraft, and MSS satellite. Thus, for segments of flight paths that include the conjunction case, large decreases in interfering signal power are possible due to the large increases in MAT antenna discrimination with off-axis angle and test aircraft distance from the conjunction point.

Table 4 - Statistics of Interfering Signal Power Due to MAT Antenna Motion With the Test Aircraft Near Maximum Range From the MAT Receiver

Interfering Signal Power Level (I) Relative to Peak for Geometry 2	2.44 Meter MAT Receiver Antenna		10 Meter MAT Receiver Antenna	
	Cumulative Probability	C/N Reduction [N+I]/N (dB)	Cumulative Probability	C/N Reduction [N+I]/N (dB)
-0.5 dB	0.169	1.1	0.169	0.3
-1.0 dB	0.129	1.0	0.129	0.3
-1.5 dB	0.088	0.9	0.088	0.2
-2.0 dB	0.045	0.8	0.045	0.2
-2.5 dB	0.000	0.7	0.000	0.2
-3.0 dB	Interference always exceeds peak-3 dB level	Not Applicable	Interference always exceeds peak-3 dB level	Not Applicable
-3.5 dB				
-4.0 dB				

Table 5 - Statistics of Interfering Signal Power Due to MAT Antenna Motion With the Test Aircraft Near the Minimum Range From the MAT Receiver

Interfering Signal Power Level (I) Relative to Peak for Geometry 2	2.44 Meter MAT Receiver Antenna		10 Meter MAT Receiver Antenna	
	Cumulative Probability	C/N Reduction [N+I]/N (dB)	Cumulative Probability	C/N Reduction [N+I]/N (dB)
-3 dB	9.994	22.7	1.000	22.7
-6 dB	0.988	19.7	0.999	19.7
-9 dB	0.982	16.7	0.999	16.7
-12 dB	0.976	13.8	0.999	13.8
-15 dB	0.970	11.0	0.999	11.0
-18 dB	0.809	8.3	0.999	8.3
-21 dB	0.674	5.9	0.998	5.9
-24 dB	0.424	3.9	0.988	3.9
-27 dB	0.000	2.4	0.979	2.4
-30 dB	Interference power always exceeds peak-3 dB	Not Applicable	0.964	1.3
-33 dB			0.937	0.7
36 dB			0.890	0.4
-39 dB			0.809	0.2
-42 dB			0.669	0.1
-45 dB			0.424	0.0
-48 dB			0.000	0.0
-51 dB			Always exceeded	Not Applicable

4.3 Joint Statistics

Because the MSS signal level at the MAT receiver (I) varies slowly and the desired signal (C) varies rapidly in relation to the 10 second interval assumed for measurement of MAT availability, it would be misleading to simply convolve the long-term probability density functions for the desired signal C and the degradation 1/[N+I] in order to determine the statistics of C/[N+I]. However, the variation in MSS signal power (Tables 4 and 5) establishes certain "degrees of confidence" with respect to local minimum C/[N+I] values established under Geometries 1 and 2. The degree of confidence can be interpreted as a certain spatial availability (as opposed to temporal availability). This approach preserves the short-term temporal statistics of C/[N+I] for comparison with the threshold level described in Section 2. Specifically, the C/[N+I] statistics based on the local peak interfering signal level and the statistics of desired signal power for Geometry 1 or 2 can be extended to all MAT geometries involving the same separation distance between the MAT receiver and the test aircraft (i.e., distances near the maximum distance in the case of Geometry 1, and distances near the minimum distance in the case of Geometry 2). For Geometry 1, however, the low variation of interfering signal power with MAT antenna motion (and the test aircraft at maximum range) yields only small differences among the C/[N+I] values obtained for high degrees of confidence.

The statistics of C/[N+I] are given in Tables 6 and 7 for Geometries 1 and 2, respectively. For Geometry 2 (Table 7), the results include C/[I+N] levels that will be exceeded with a 99% degree of confidence (spatial availability). In Geometry 1, the C/[N+I] values for 99% and 100% degrees of confidence are almost equal; the C/[N+I] values in Table 6 are for 100% degree of confidence because they reflect only temporal statistics and the spatial minimum C/[N+I] levels.[3]

Table 6 - Statistics of C/[N+I] for Low Performance MAT Links With the Test Aircraft Operating Near Maximum Range (Geometry 1)

Temporal Probability of C/[N+I] Level Being Exceeded (% of time)	Performance With 2.44 Meter MAT Antenna C/[N+I] (dB)	Temporal Probability of C/[N+I] Level Being Exceeded (% of time)	Performance With 10 Meter MAT Antenna C/[N+I] (dB)
1.3	31.0	1.3	44.8
11.3	28.0	25.2	39.8
33.5	25.0	64.7	34.8
57.8	22.0	87.1	29.8
76.0	19.0	95.7	24.8
87.1	16.0	98.6	19.8
93.3	13.0	99.6	14.8
94.7	12.0	99.7	12.0
96.7	10.0	99.8	9.9

Table 7 - Statistics of C/[N+I] for Low Performance MAT Links With the Test Aircraft Operating Near Minimum Range (Geometry 2)

Temporal Probability of C/[N+I] Level Being Exceeded (% of time)	C/[N+I] (dB) (100% Degree of Confidence)	C/[N+I] (dB) with a 2.44 m MAT antenna exceeded with 99% Degree of Confidence (spatial probability)	C/[N+I] (dB) with a 10.0 m MAT antenna exceeded with 99% Degree of Confidence (spatial probability)
3.1	30.0	30	30
17.6	27.0	30	30
41.9	24.0	29	30
64.7	21.0	26	30
80.4	18.0	23	30
89.6	15.0	20	30
94.7	12.0	17	30
97.3	9.0	14	30

[3] Note: according to the criteria in Section 2, the C/[N+I] must exceed 12 dB with probabilities of at least 0.934 and 0.997 for the 2.44 meter and 10.0 meter MAT antennas, respectively. These criteria are met in Table 6 and in Table 7 (for a 99% degree of confidence in the case of the 10.0 meter MAT antenna).

5. INTERFERENCE TO MOBILE EARTH STATIONS

Figure 2 presents the nominal distance separations required between a mobile earth station and an MAT transmitting aircraft. Co-channel operation and the parameters in Table 1 are assumed, and the effect of MSS receiver filtering of the relatively wideband MAT signal is included. The basic transmission losses that were applied are exceeded for 5% of the time on a high performance air-to-ground link (i.e., little or no blockage) (ITU-R Recommendation 528-2).

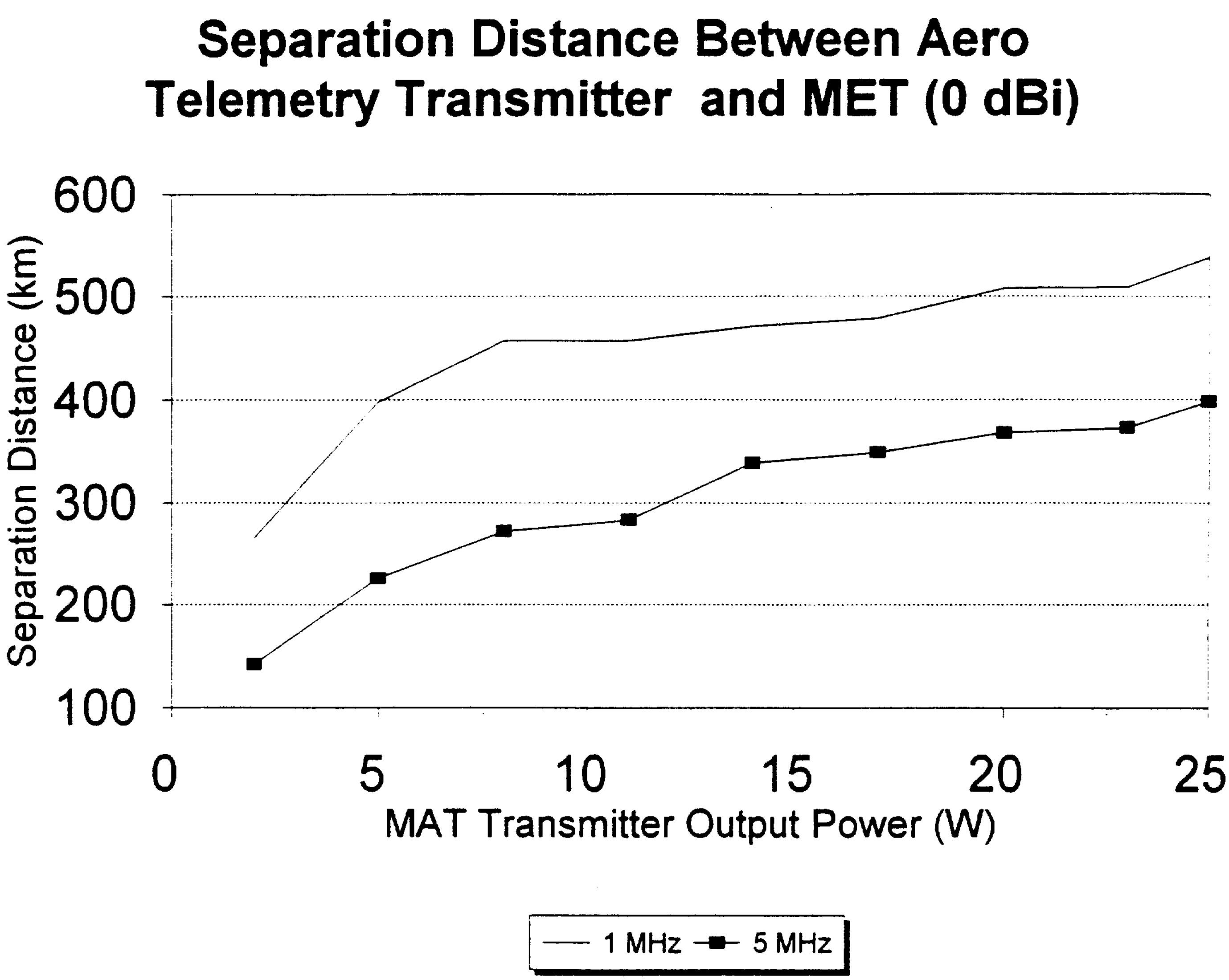

Figure 2 - Nominal required separation distances between co-channel mobile earth stations and MAT transmitters

6. CONCLUSIONS

6.1 Co-Channel Sharing in the Same Geographic Area

Comparison of interference criteria for MAT links (Section 2) with the results in Tables 6 and 7 indicates that one co-channel MSS signal would not cause unacceptable interference with a MAT system under the pessimistic assumptions that have been made (i.e., interference is over-stated). Specifically, with the MAT aircraft at maximum range transmitting to a 2.44 meter antenna, the 12 dB C/N threshold occurs with and without the MSS signal being present with probabilities of 0.947 and 0.957, respectively. With the aircraft at maximum range transmitting to a 10.0 meter antenna, the 12 dB C/N threshold occurs with and without the MSS signal being present with a probability of 0.997. Likewise, the sharing criteria are met with the MAT aircraft at minimum range from either a 2.44 meter or 10.0 meter antenna.

As shown in Section 5, large separation distances are needed to protect mobile earth stations from co-channel MAT transmissions. More detailed analysis is unlikely to yield co-channel separation distances substantially smaller than those in Figure 2. Consequently, off-tuning of MSS frequencies from MAT carrier frequencies may be necessary to achieve separation distances that are small enough to be negligible (i.e., distances yielding a small probability of interference). Potential solutions to this problem are addressed below (Sections 6.2 and 6.3).

6.2 Sharing in the Same Geographic Area With Off-Tuned MSS and MAT Carriers

Because the assumed MSS signal has a bandwidth that is much smaller than typical MAT signals, the interfering signal power in the demodulator of a MAT receiver is reduced with increasing off-tuning of the carriers in accordance with the overall RF-to-demodulator filter attenuation. Likewise, the interfering signal power in the demodulator of a MSS receiver is reduced with increasing off-tuning of the carriers in accordance with the spectral power distribution of the MAT signal. Thus, by off-setting MSS and MAT carrier frequencies, the potential interference between MSS and MAT systems can be greatly reduced. This effect is referred to as Off Tuning Rejection (OTR). For example, by off-setting carriers by about one-half the MAT signal bandwidth, upwards of 20 dB of OTR would be typically available to facilitate sharing. This OTR would yield at least a 10-fold reduction in separation distances needed to protect mobile earth stations and upwards of a 100-fold increase in the number of MSS channels that could be accommodated without interference to the MAT link.

6.3 Sharing in the Same Geographic Area With Multiple Off-Tuned MSS Carriers

It is likely that the cross-section of links that must be operated at the same time across the 1435-1535 MHz telemetry band in a given area will include links with high, medium and low performance (Table 2), which establishes the possibility that low performance links that are least tolerant of interference can be accommodated at unshared frequencies. However, the results do not indicate that this type of frequency planning is required to protect MAT links, particularly if off-setting of carrier frequencies is used to protect MSS operations. MSS and MAT frequency plans could be arranged to accommodate several MSS channels between each of several adjacent MAT channels such that sufficient OTR is available to prevent interference. This approach could be based on the MAT channel standards in Ref. 5 and modifications to MAT channel assignment practices. Consider, for example, the MAT "Standard Channels" with 1 MHz bandwidth, which can be sub-divided into 100 kHz "Narrow-Band Channels" or grouped to form "Wide Bandwidth Channels." By pre-designating certain segments of the 1492-1525 MHz band for standard, narrow-band, and wide bandwidth MAT channels, MSS operators could accommodate MSS channels in small clusters (e.g., 13 MSS channels) interstitially with respect to MAT channels. (Moreover, the effects of MSS downlink transmission duty factors may become influential when considering multiple MSS channels.) The MAT channels could be pre-designated permanently or temporarily (e.g., daily, with notice to MSS operators) in order to facilitate this sharing approach.

6.4 Effect of Geographic Separation

The PFD levels falling outside a given MSS satellite antenna beam will be substantially lower than those in the beam coverage area, which would reduce the potential interference to MAT links operating on or near the MSS beam frequencies. Consequently, assume for example that 13 MSS channels could be accommodated between two MAT channels that are operated in the MSS beam coverage area. The potential interference to those MAT channels would not be 13 times higher if the 13 channels divided among two or more non-overlapping MSS satellite antenna beams. This "geographic sharing" approach may enable several tens of MSS channels to be accommodated between MAT channels.

6.5 Effect of Satellite Location

The MSS satellite considered herein was assumed to be located at 101° W.L., which yields favorably high elevation angles (40°) from the MAT receivers to the satellite. Use of other satellite locations more than ±10° to the east or west of the assumed location could result in significantly higher interference to certain MAT receivers (i.e., those having relatively low elevation angles to the assumed satellite location). At some locations, OTR must be achieved in order to prevent interference to MAT links from only one MSS downlink carrier. The sharing possibilities for alternate satellite locations should be evaluated on a case-by-case basis.

REFERENCES

1a. "Spectrum Resource Assessment of the Aeronautical Mobile Service Between 400 MHz and 17.7 GHz," National Telecommunications and Information Administration, PB85-125995, September 1984.

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2. Background paper on AMSC interests in the 1492-1530 MHz band (dated 26 May 1993)

3. "Coordination Threshold and Techniques for the Protection of Mobile Aeronautical Telemetry Systems in the Band 1452-1525 MHz," ITU-RS Doc. 8D/157 (+Add1), dated 20 September 1993.

4. "Telemetry Applications Handbook," Range Commanders Council, Telemetry Group, Doc. 119-88, February 1988.

5. "Telemetry Standards," Range Commanders Council, Telemetry Group, Doc. 106-93, January 1993.

ATTACHMENT 1

ANALYSIS APPROACH

A. Calculation of Unfaded C/N of Aeronautical Telemetry Link

Equations 1 through 3 pertain to the MAT link operating in the absence of an MSS signal. The distance and elevation angle from receiver to the aircraft are calculated using Equations 1 and 2, respectively. The carrier-to-noise ratio at the input of the MAT receiver is calculated using Equation 3.

$D = [6378^2 + (6378 + alt)^2 - 2(6378)(6378 + alt)\cos(range/6378)]^2$, for Geometry 1 (1a)

$D = [6378^2 + (6378 + alt)^2 - 2(6378)(6378 + alt)(\cos\zeta)(\cos\beta)$ (1b)

$E = \cos^{-1}[\{(6378 + alt)\sin(range/6378)\}/D]$, for Geometry 1 (2a)

E = (see Equation 6), for Geometry 2 (2b)

$$\frac{C}{N} = P_t + G_t - 20\log(D \cdot f) - 32.45 + G_r - 10\log N \quad (3)$$

$$N = kTB \quad (4)$$

where:

- D = length of signal path (km) in the MAT link;
- alt = height of the aircraft (km);
- range = maximum operational great circle path distance (km) between the aircraft and the MAT receiver;
- ζ = latitude of the MAT receiver (degrees);
- β = difference in longitudes of the MSS satellite and MAT receiver (degrees);
- E = elevation angle at the MAT receiver antenna toward the aircraft (degrees);
- C/N = unfaded carrier-to-noise power ratio (dB) at the MAT receiver input;
- P_t = antenna input power (dBW) at the test aircraft;
- G_t = nominal transmitter antenna gain (dBi) of the test aircraft;
- f = MAT frequency (MHz);
- G_r = mainbeam gain of the MAT receiver antenna (dBi);
- N = thermal noise power (watts) at the MAT receiver input;
- k = Boltzmann's constant, 1.38E-23 (J/K);
- T = thermal noise temperature (K) at the MAT receiver input;
- B = MAT receiver bandwidth (Hz).